Resolving Complex Flows in a Reef/Island Environment

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LONG-TERM GOALS

While reef/island areas have traditionally been difficult to sample, new platform and sensor technology afford the opportunity to systematically study the complex flows in and around these systems, and the influence of wind, waves, tides, bottom topography, bottom roughness, and internal waves on these processes. Recent deployments of the REMUS UUV in coastal California waters demonstrate the ability of this platform to operate routinely in very shallow water (VSW) environments, such as ports and harbors and the near shore/surf zone transition. The fine-scale flows will be resolved in conjunction with bottom mapping and characterization and time series measurements. These data will advance our understanding of the forcing mechanisms governing the temporal and spatial in these environments, provide a benchmark data set for testing hydrodynamic models, and provide operational guidance for conducting UUV surveys in regions of complex flows and topography.

OBJECTIVES

Our objective [in collaboration with Eric Terrill (SIO) and Lyle Hibler (PNNL)] is to use UUV systems to systematically map regions of interest in and around reed, atoll, and island systems to improve characterization of flow fields, the influence of bottom type on these flows, and the influence of tides and waves in these systems. Data from multiple deployments of UUVs in addition to fixed platforms will provide the initiation data for a DELFT-3D FLOW modeling effort that will attempt to best characterize the complex flows in these environments.

APPROACH

We propose to make a series of observational campaigns off the islands of Palau to define the flow and characterize bottom type in and around the reef/island environment. We will use an existing set of REMUS UUV platforms and time series to measure at scales of O(1 hr) and O(10-100m). The fine-scale flows will be resolved in conjunction with bottom mapping and characterization and time series measurements. These data will advance our understanding of the forcing mechanisms governing the temporal and spatial in these environments, provide a benchmark data set for testing a hydrodynamic model, and provide operational guidance for conducting UUV surveys in regions of complex flows and topography.

We will conduct UUV-based surveys to characterize ocean conditions and bottom type over the scales in this complex environment. We will develop optimal methods for executing surveys in regions of

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high currents and in regions of rapid changes in bottom relief (eg – coral heads). Surveys will include both physical oceanographic measurements (velocity, temperature, salinity) and bottom surveys using imaging and sidescan sonar.

In order to conduct this work, we will use 4 ONR-funded REMUS UUVs (Moline et al. 2005). The REMUS is a propeller-driven platform that in this application will navigate relative to seafloor transponders located throughout a network area, allowing for multiple flight path options within the defined volume space. The small size allows for easy transportation, and may be launched and recovered from a small vessel or pier without special handling equipment. Both Scripps and Cal Poly have significant experience with the REMUS vehicles, with proven routine operation in VSW environments as shallow as 2 meters. The vehicle has also shown its ability to maintain position and flight lines parallel to shore in the breaker zone. The vehicles are outfitted with CTDs, fluorometers, optical backscatter sensors, up- and down-looking 1200kHz ACDP, imaging hardware, and side scan sonars.

The ADCPs and self-contained water level (waves/tides) and temperature sensors will be deployed at regions TBD to characterize the flows within the reef environment. Sensors will be deployed for a nominal 1 year turnaround cycle, with the potential for a 6 month turnaround should local support be available from scientists based out of Palau. A temperature chain will be deployed near the outer boundary of the model domain (the foreslope of the reef) in waters nominally 50-100m to provide observations of the internal tide prior to impingement on the complex topography. These data will also be used for registering the ocean state at the reef with respect to larger-scale synoptic measurements taking place in the region (e.g. – glider surveys by D. Rudnick of the origins of the Kuroshio).
We will develop and operate a DELFT-3D model of the observation area to test the predictability of the flows, and use the model as a diagnosis tool for examining the influence of forcing terms (i.e. roughness) on the flow field. There are two research challenges related to the proposed model approach: 1) the evaluation of the existing applied circulation model with appropriated accounting for the range of flow phenomena associated with reef and reef lagoon and coastal systems, and 2) the adaptation of recent formulations in DELFT3D-FLOW for characterizing reef as roughness elements in an applied model.

The recent modifications to DEFLT3D-FLOW include a more advance treatment for bed roughness which can account for grain size distribution of bed sediment, bedforms and vegetation. A combination of these can be accounted for each computational cell. For an applied circulation model where lagoon and coastal water exchanges are to be examined, the computational cells will have lengths scales from 10-100 meters. Whereas the scale of a coral colony volume can be from 10^{-3} to 30 m^3 and reef boundary layers have length scales of 1 to 10 meters (Monismith, 2007). An important research question will be how to effectively incorporate coral reef features as roughness elements using the recent enhancement to DELFT3D-FLOW with the recognition that the coral reef features will likely be sub-grid scale.

WORK COMPLETED

The objectives of this first year of the project were to 1) identify the study area, 2) conduct preliminary UUV surveys to measure seafloor roughness and water velocity, 3) deploy temperature/pressure sensors and ADCPs, 4) and begin development of DELFT-3D FLOW model grid and use available data. Since the beginning of this project in February, 2010, we have achieved all of these objectives. After Palau was identified as the study site, in part because of the leveraging of the origins of the

Kuroshio project (PI: D. Rudnick), we conducted a field campaign in March, 2010. During this field effort, we identified key locations around the island group to characterize flow (Figure 1). These were areas of known high tidally driven flow, across reef flats, and transitioning from oceanic settings to river systems. We also placed temperature/pressure sensors along the island chain to start obtaining a time series.

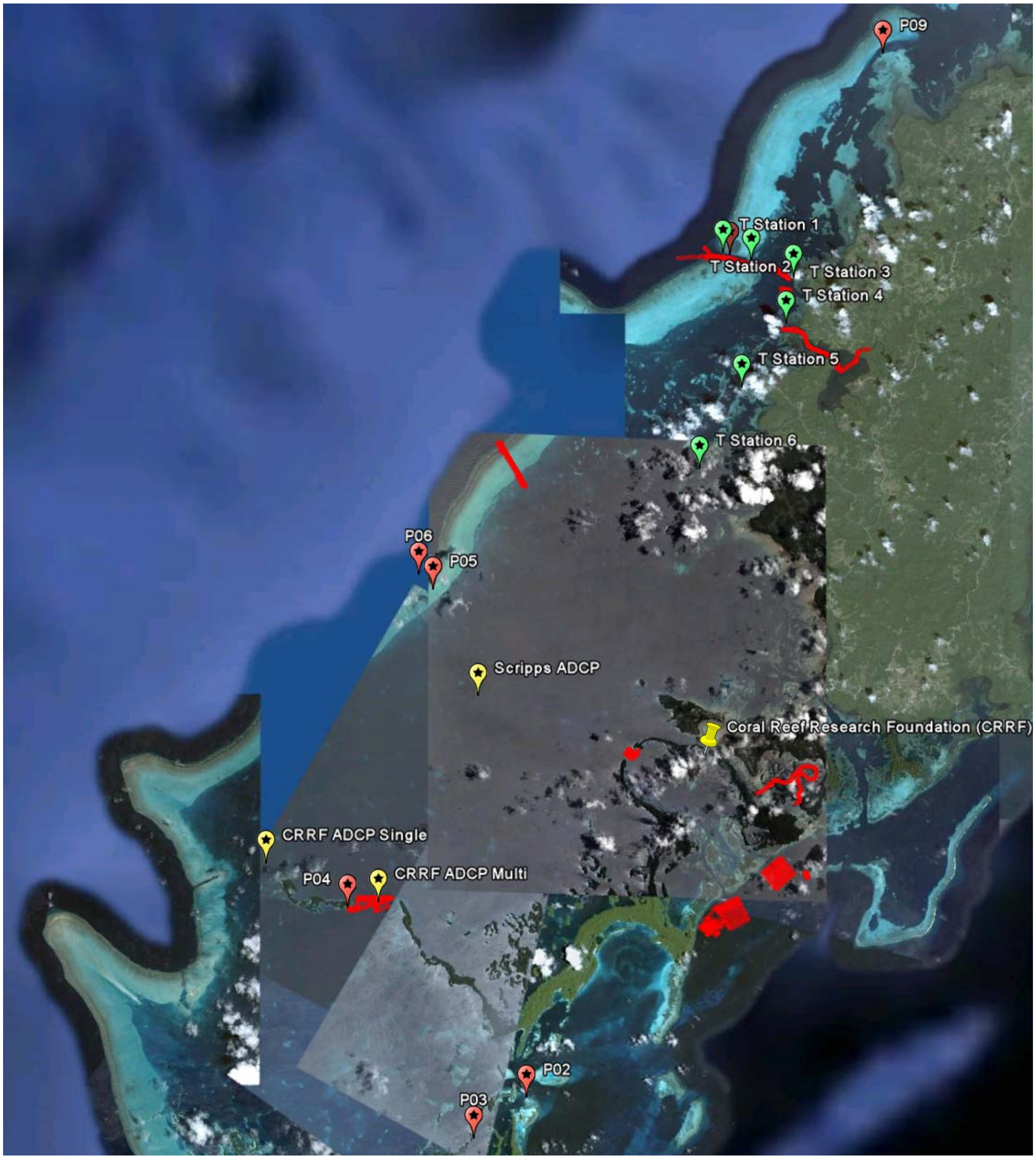

Figure 1. Spatial sampling of the UUVs around the island group of Palau (red). Temperature sensors deployed are marked as green balloons. Pressure sensors to evaluate gradients are marked as red balloons. Two ADCPs deployed during the March, 2010 field effort are marked as yellow balloons. The distribution of these assets attempted to characterize areas of high flow, reef flats and transitions from oceanic conditions to river systems.

RESULTS

While recently collected data is still being processed, analyzed and prepared for incorporation into DELFT-3D FLOW, preliminary results highlight the capability of these UUV to operate effectively in these environments. This includes shallow water (~1m deep), in strong tidally-driven currents in access of 1.5 ms^{-1}(Figure 2), and highly capable navigation in narrowly (10-20m) spaced islands and from oceanic settings to river systems (Figure 3).

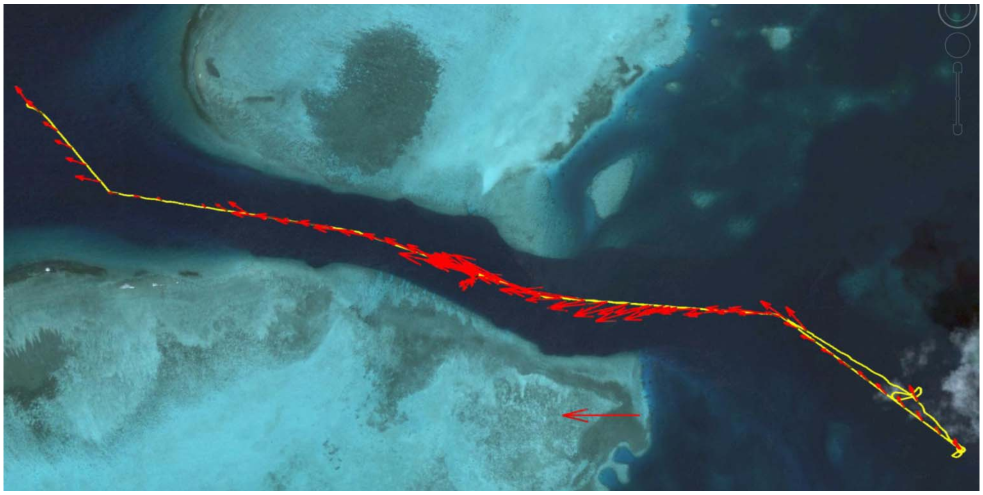

Figure 2. Current flow in the West Channel obtained from a UUV approximately 10m off the bottom of this 80m-deep channel. The reference arrow indicates 1 ms^{-1} flow. Over this maximum tidal exchange, the vehicle was able to navigate well and measured mean currents of $0.5m^{-1}$near the bottom.

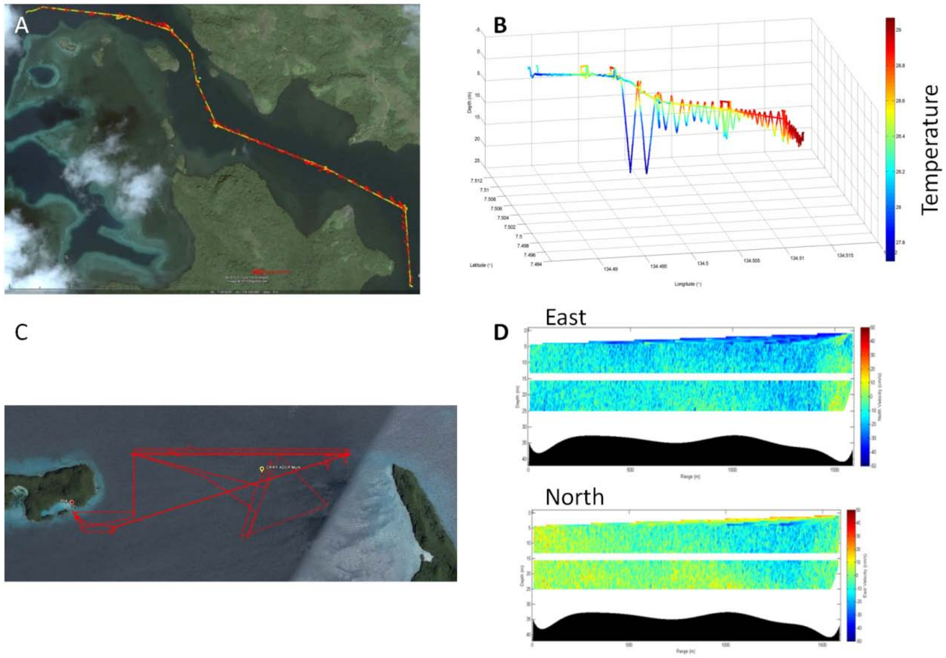

Figure 3. A) Navigation from oceanic conditions into the estuary by the UUV in an outgoing current (~0.1 ms^{-1}), with a small, but detectable difference in temperature of 0.3°C (B) and 2 ppt salinity. (C) the Ulong channel in the middle portion of the Palauan island group was characterized for flow by the UUVs during the maximal tidal excursion and was found to be highly asymmetric with flow to the southwest on the eastern side and south on the west side (D).

The DELFT-3D FLOW model grid has been preliminarily rendered with bathymetry from the local hosts (Coral Reef Conservation Foundation) with tides as the only input. Results from the ADCPs and temperature/pressure sensors will follow the instrument retrieval planned for March, 2011. As data become available, we will work to refine this model and define the grid spacing needed to approximate the measured flows in the field.

IMPACT/APPLICATIONS

These data will advance our understanding of the forcing mechanisms governing the temporal and spatial flow regimes of reef, island and atoll environments, and provide a benchmark data set for testing a hydrodynamic model, and provide operational guidance for conducting UUV surveys in regions of complex flows and topography.

TRANSITIONS

None to date

RELATED PROJECTS

Resolving complex flows in a reef/island environment N000141010678 (PIs: E. Terrill and L. Hibler)
Origins of the Kiroshio (PI: D. Rudnick)

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PUBLICATIONS

None.

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